MARS DROP

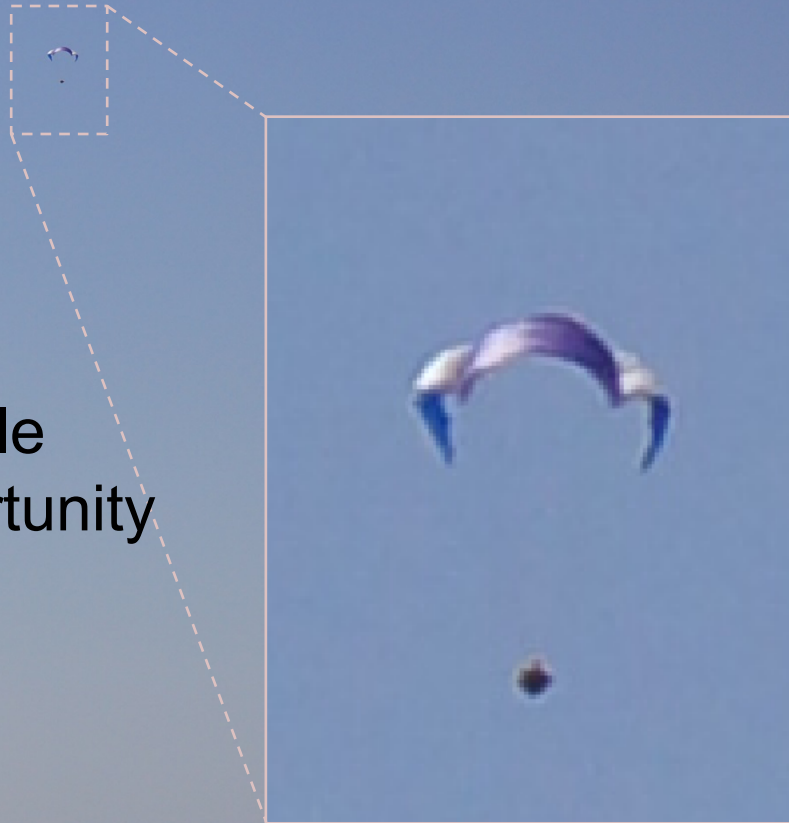## MARS_DROP Architecture:
MicroLanders to Enable Multiple
Landings At Every Mars Opportunity

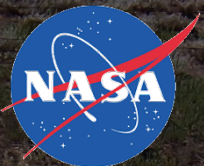**2014 November 21**
Mars CubeSat/Nanosat Workshop
California Institute of Technology

Robert L. Staehle/Jet Propulsion Laboratory-California Institute of Technology
Matthew A. Eby/Aerospace Corp., Rebecca M. E. Williams/Planetary Science Institute
Rohit Bhartia, Justin Boland/JPL-Caltech

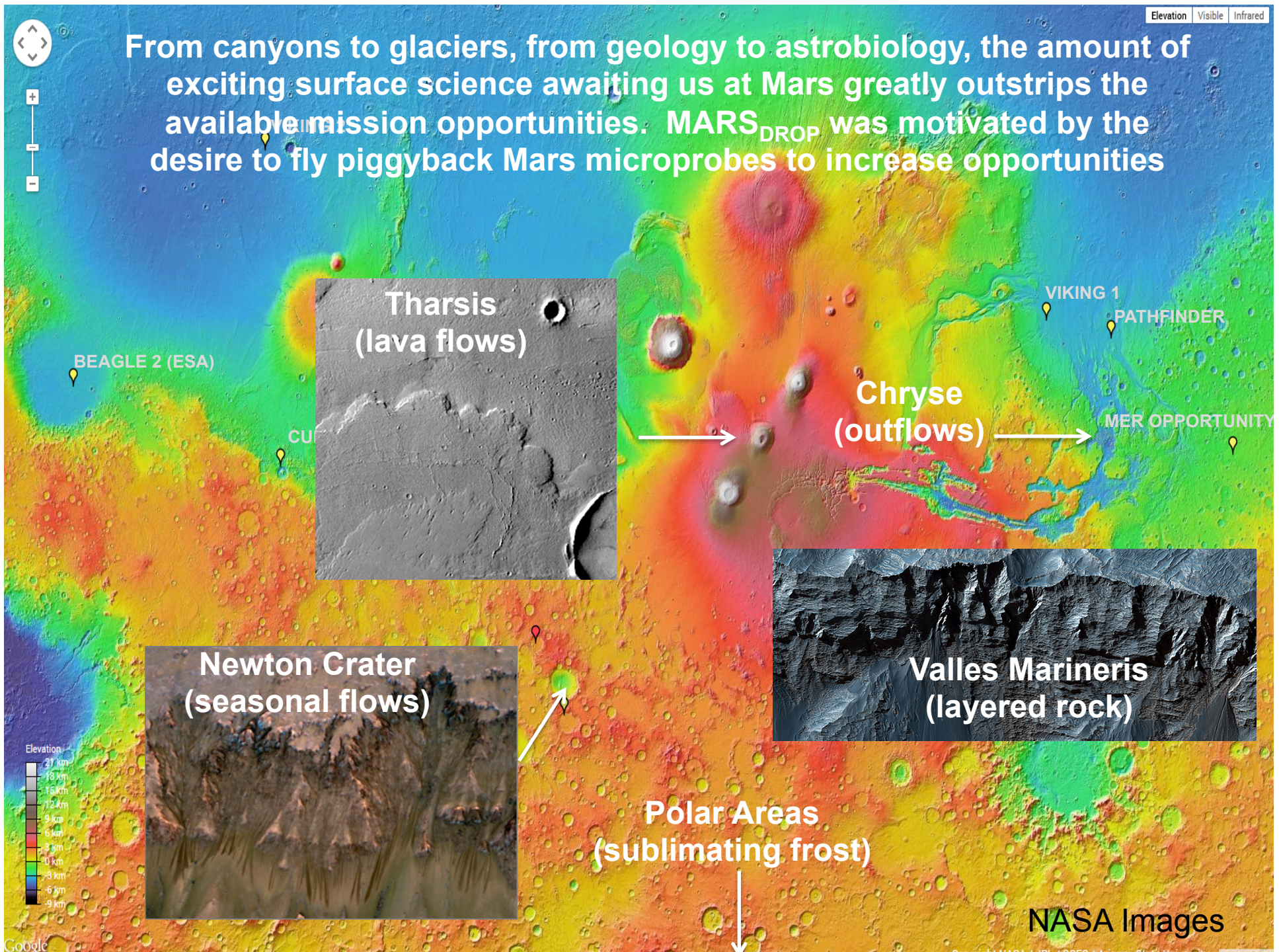Further example Payload Contributions from: Courtney Duncan, Travis Imken/JPL

NASA

AEROSPACE

Planetary Science Institute

From canyons to glaciers, from geology to astrobiology, the amount of exciting surface science awaiting us at Mars greatly outstrips the available mission opportunities. MARS$_{DROP}$ was motivated by the desire to fly piggyback Mars microprobes to increase opportunities

Tharsis (lava flows)

Chryse (outflows)

BEAGLE 2 (ESA)

VIKING 1
PATHFINDER

MER OPPORTUNITY

Newton Crater (seasonal flows)

Valles Marineris (layered rock)

Polar Areas (sublimating frost)

NASA Images
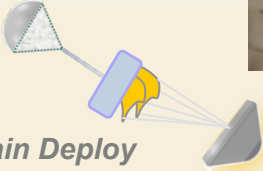
Landing Architecture

Entry Interface
100 km, V=7km/sec

T+1 min, Max Q
35 km, 15 g's

T+3 min, Backshell Sep.
6.5 km, Mach 0.85

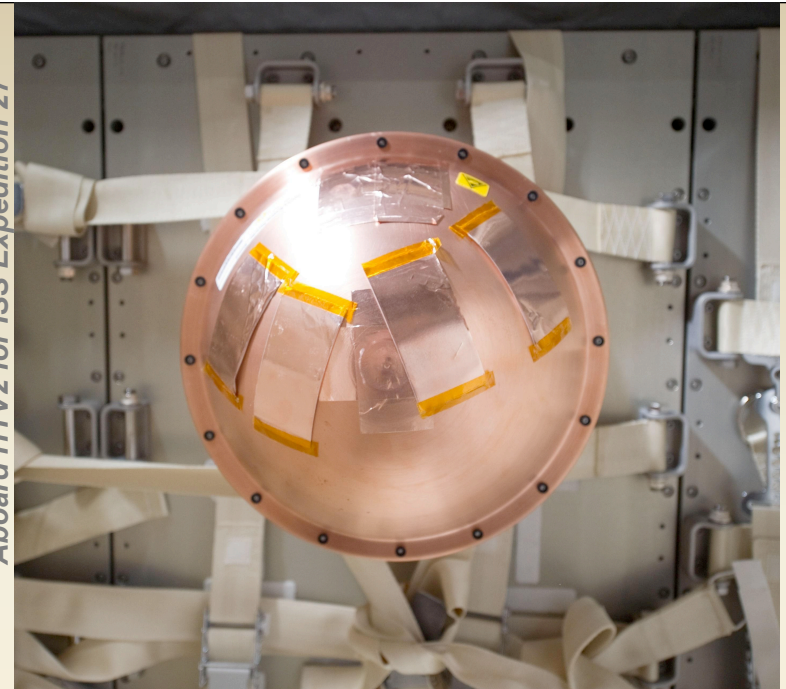**T+3 min, Main Deploy**
6.5 km, 200m/sec

3-DOF Simulation
(Range, Height, Orientation)
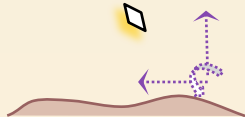
T+3 min, Peak Inflation Load
6.5 km, 65 g's

T+10 min, Terminal Landing
3.0 km, Vertical < 7.5 m/sec

Foreground & REBR Images Courtesy of NASA

Capability Summary

- Probe is largely inert ballast from the host standpoint, added burden of 10 kg per probe

- Probe shape derived from REBR/DSII, provides passive entry stability

- Entry mass limited by the need to provide a subsonic parachute deployment

  - *3-4 kg probe entry mass*

  - *Accommodates a ~1 kg science payload*

- Packed chute preserves a significant portion of the volume for a landed payload

- Parawing is potentially steerable, opening the way for targeted landing

  - *New missions enabled*

- Inexpensive, $20-50 million per mission

  - *Encourages high risk destinations, such as canyons*
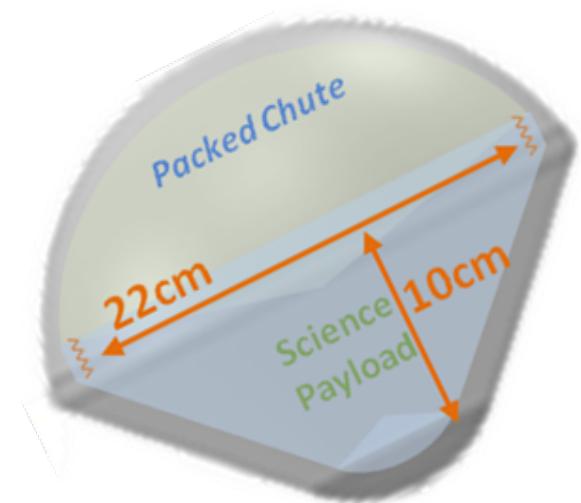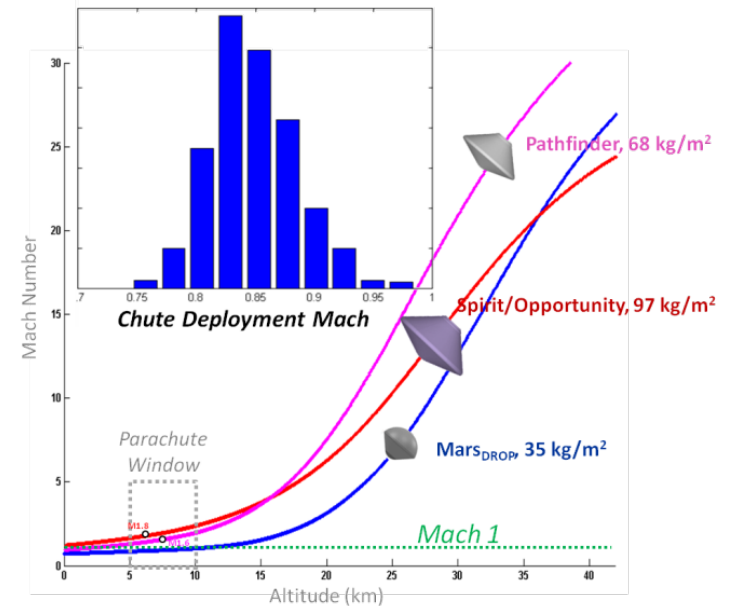
Aerodynamic Decelerator Optimized for Volume, Scaled Down from a Gemini Parawing Design

Concepts:	Solid Circular Parachute	Disk-Gap-Band Parachute	Inflatable Decelerator	Vortex Ring Parachute	Parawing ✓
Claim to Fame	"Standard" Round Solid Parachute	Used on all NASA Mars Landers	Targeted for future NASA Mars Landers	Highest Drag	Gliding Chute
Supersonic	No	Yes	Yes	Unreliable	No
Complexity	Low	Low	High	High (Swivel)	Medium
Prior Research	Extensive	Extensive	Moderate	Minimal	Moderate
Subsonic Drag	Moderate ($C_D \sim 0.9$)	Low ($C_D \sim 0.6$)	Moderate ($C_D \sim 0.8$)	Very High ($C_D \sim 2.0$)	Very Low ($C_D \sim 0.3$), but Lift
Mass / Volume for 7.5m/s vertical velocity (reference V)	1.1 kg / 2300 cm³	1.7 kg / 3480 cm³	2.5 kg / 5200 cm³	0.5 kg / 1050 cm³	0.2 kg / 200 cm³
Notes / Landing Site Limitations		Poor subsonic drag prompts two-stage deceleration	Is attractive for much larger vehicles	Suspect Reliability	Horizontal velocity -could be good or bad

NASA Photo

Going to Mars on Earth

Release

Target Drop Altitude 90k – 100k feet

Accelerate to Q

Conduct Test

Launch

Photo by Lori Paul

Recovery Tracking
Beacon, Position & Telemetry
144.39 MHz & 430 MHz

| Flight	Test Objective	Setup	Drop Altitude	Chute Deploy V	Chute Deploy Q	Canopy Condition	Test Result
MARS$_{DROP}$ 0 *(May 2013)*	Launch, Tracking, Recovery	Only Flight Computer	104,000	N/A	N/A	N/A	Experimental Setup Checked
MARS$_{DROP}$ 1 *(May 2013)*	Parawing Deployment	Chute Bomb	80,000	-	-	-	Electrical Short-No Parawing Deployment
MARS$_{DROP}$ 2 *(Sept. 2013)*	Parawing Deployment	Chute Bomb	100,500	300 mph	200 Pa (On Target)	No Damage	Successful Inflation, Backshell Tangled with Lines Post Deployment
MARS$_{DROP}$ 3 *(Feb. 2014)*	Capsule Demonstration	Capsule	115,000	500 mph	410 Pa (Overtest)	No Damage	Capsule Oriented Backwards-Canopy Inverted at Deployment
MARS$_{DROP}$ 4 *(May 2014)*	Capsule Demonstration	Capsule	114,000	550 mph	580 Pa (Overtest)	Minor Damage-Wing Tip Line Snapped	Successful Inflation & Deployment from Capsule-New Packing Procedure Verified

A Technology Demonstration Mission

- A low cost demonstration mission could be mounted in the near future based largely on existing elements:

  – *Cruise stage carrier brackets borrowed from Mars Polar Lander design.*

  – *Aeroshell derived from REBR/DSII.*

  – *Flight computer borrowed from Aerospace/JPL CubeSats.*

  – *Iris-based radio.*

  – *COTS imaging descent camera.*

- Once demonstrated, several piggyback probes can go with each Mars-bound craft at minimal added cost & mass.

  – *Instrument technology survey identified a wide range of plausible payloads.*
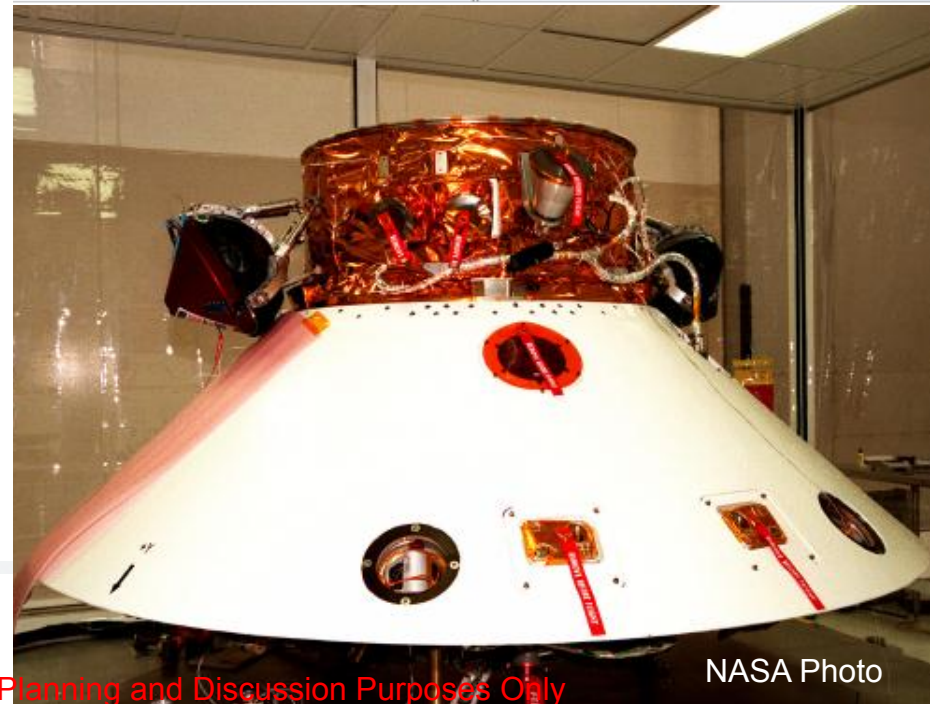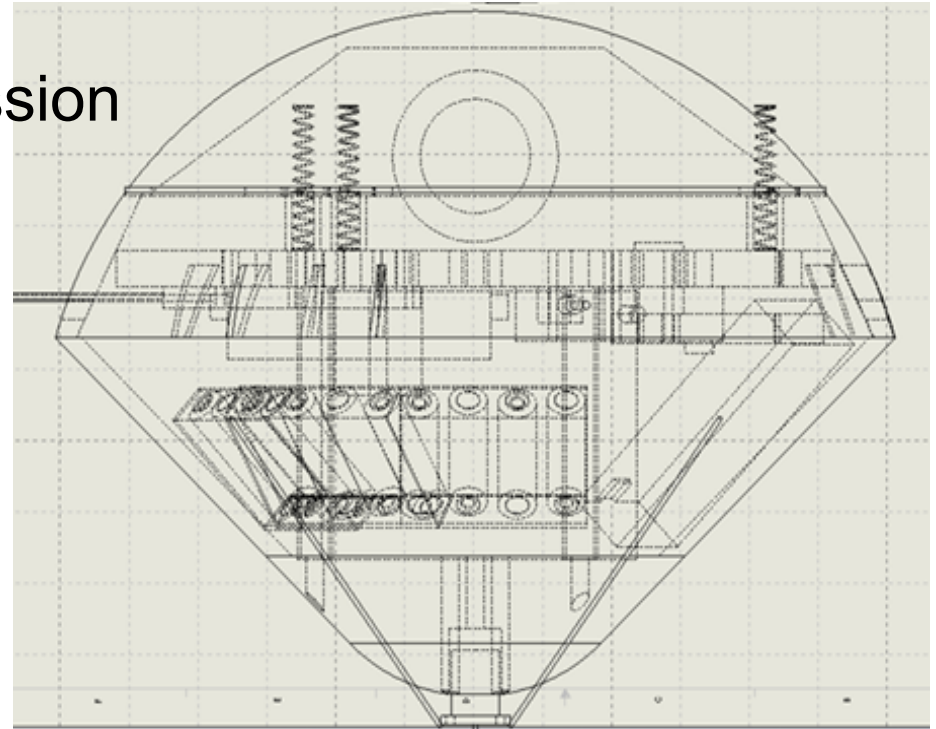
NASA Photo

Survey: A Variety of Plausible Instrumentation, Serving a Span of Science, Can Be Accommodated

Instrument Type	Mass (g)	Power (mW)	Max Dimension (mm)	Example	Modifications Required	Measurements & Remarks	POC/JPL Org
Video Camera	74	600-1900	60	GoPro Hero3	Rad tolerance; modify for external control	720p, 960p, 1080p video with 3 FOVs up to ~150 deg. 5, 7, 10 MP pictures with 3 - 10 fps.	T. Imken/ T. Goodsall
Legacy still camera	220	215	67	MER/MSL Hazcam & Navcam	Lander to provide input voltages and camera control	High heritage; scientific quality CCD still images up to every 5 sec. >20 units to Mars.	M. Walch
SmartCam	<100	< 1600	58	PIXHAWK	Low op temp, Rad tolerance.	Machine vision camera and processing to support glide-to-target guidance.	J. Boland
uSeismometer	200	100	30	JPL Microdevices		Performance comparable to conventional terrestrial seismometer.	R. Williams/PSI
Weather Monitor	≤1930	12,750 (peak)	140	REMS/MSL, Twins/InSIGHT	Adapt to the desired envelope.	Configuration is flexible and sensors can be added or subtracted/replaced + dust sensor via a dedicated camera..	M. de la Torre Juarez
Aerosol Properties Sensor	630	4300 (peak)	70	REMS/MSL, Twins/InSIGHT	Adapt to the desired envelope.	(included above)	M. de la Torre Juarez
Multispectral Microscopic Imager VNIR	240	3000 (60 sec.)	67	MER-MI Rosetta ROLIS Phoenix RAC	Wider FOV	Infer mineral grain composition at <1 mm scale. Operates day (panchromatic) or night (multispectral 0.4 to 1.0 microns).	R. Glenn Sellar
Multispectral Microscopic Imager VSWIR	150	9000 (5 mins)	110	MMI Mars 2020 proposal	Wider FOV ~ 30 x 30 cm. Consider COTS InGaAs camera	Infer mineral grain composition at <1 mm scale. Passively-cooled HgCdTe - operates at night (multispectral 0.45 to 2.45 microns).	R. Glenn Sellar
Deep UV Fluorescence Imager	700	3000 (peak)	150	Lab demo	Communication/power from vehicle.	Organic detection. Small UV light sources dependent on current DARPA efforts.	R. Bhartia
Deep UV Fluorescence / Raman Imager	3000	15000 (peak)	250	SHERLOC/ Mars 2020	Reduce mass, comm/power from vehicle	Organic detection, astrobiological-relevant minerals, Ops short burst laser source high TRL.	R. Bhartia
Iris 2+ Transponder	700	12,000 (xmit)	100	Iris on INSPIRE Cubesat	Reduce mass (perhaps UHF-only), cold temp	Data downlink 8 kbps X-band direct to DSN 70 m at 1 AU; higher rates by UHF to Mars orbiting relay assets.	C. Duncan

Example Camera System with Computation for Terrain Relative Navigation

Gumstix module (left) mounted on a programming board and connected via flex cable to a 1 MP Aptina MT9V032-based camera with M12 lens (right).

The TI AM3703 DSP could run a modified version of the Mars2020 <u>Lander Vision System</u> to provide Terrain Relative Navigation better than 1 meter knowledge at landing.
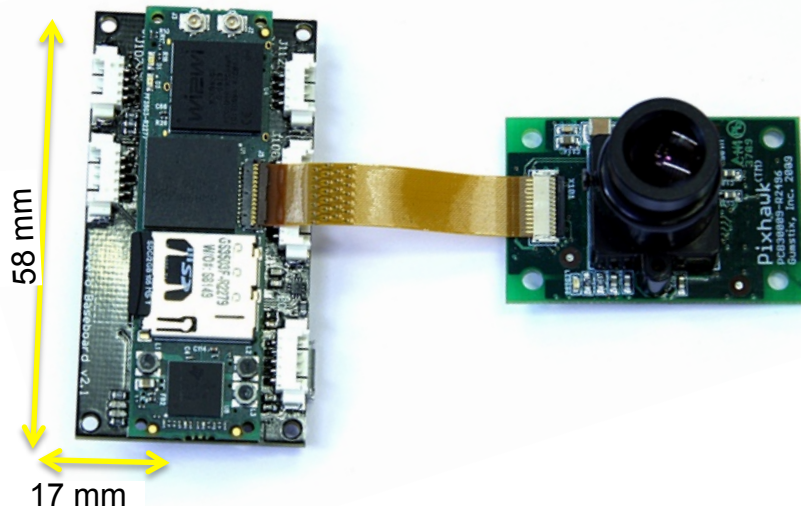

58 mm

17 mm

image source: https://pixhawk.ethz.ch/electronics/camera

- Modifications likely required:
  - Materials compatibility.
  - Modest rad tolerance (<~10 krad).
  - Thermal tolerance or heater.
  - Different pressure sensor?

Parameter	Specification
Mass, Power, Volume	33 g, 475 mW, < 6 cc
FOV, iFOV, pixels	48˚, 1 milliradian, 1 MP
framerate	60 fps
lens	4-element glass, f/4, 6 mm
Computation	TI AM3703 DSP with 1GHz ARM CORTEX A8
IMU input for Lander Vision System	MEMS Altimeter & 3-axis MEMS accelerometer

(POC: Justin Boland, Justin.S.Boland@jpl.nasa.gov)

Terrain Relative Navigation Concept Operations

1. Before launch, identify regions of high science return in existing Mars imagery.
2. At T+3 minutes, turn on camera and take image.
3. Compare to known imagery of Mars scaled for altitude and camera resolution to perform first rough location.
4. Take images at 1 frame per second, combine with attitude knowledge to improve location, velocity and attitude knowledge. Infer local winds.
5. Continuously calculate controllable landing area and steer towards closest, previously identified high science or use texture algorithms to look for high contrast areas.
6. Use optical flow algorithm to verify ground speed and improve altitude knowledge.
7. Flared landing with terrain knowledge better than 1 meter.
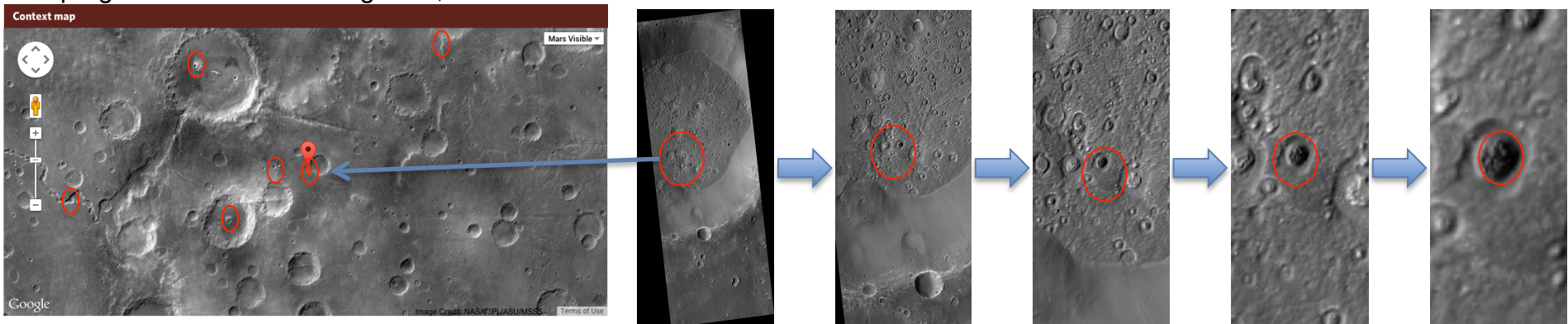
Preprogramed desired landing sites, best TRN solution

Image: HiRISE ESP_038020_1510, 51.3 cm/pixel

Example Instrument: Deep UV Fluorescence

Trace Organics/Biosignature Detection
- Deep UV (excitation <250 nm) spectroscopy is an active spectroscopic method that *enables* detection and characterization of organics and astrobiologically relevant minerals.
- Integrated visible imaging CCD context camera.
- NASA- & DARPA-supported development >15 yrs.
- ~700 g, <15W for Fluorescence *imaging*-only.

Deep UV laser induced native fluorescence
- Enables detection and differentiation of organics
  - both abiotic and biotic organics
  - Organics in meteorites (wide range of thermal maturity), and potential biosignatures.
- Maps/images organic distribution over 1cm^2
- Sensitivity at ppb.

Deep UV *resonance* Raman
- Enables detection and characterization of a wider range of organics relevant to biosignatures and alteration processes.
- Presently too large for MarsDrop microlander capability.

Current Status
- Mars 2020 – SHERLOC instrument under development;
- 3+ kg.; miniaturizing in progress
- TRL advancements for next generation sub-250 nm deep UV AlGaN sources to be developed to reduce overall size to <1kg

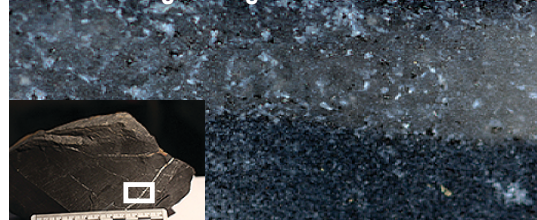(POC: Roh Bhartia rbhartia@jpl.nasa.gov/
Luther Beegle, lbeegle@jpl.nasa.gov)

Deep UV Fluorescence/Raman Instr.
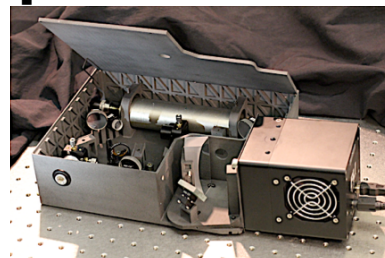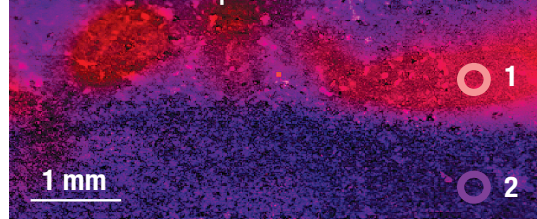

SHERLOC-Mars 2020 Prototype

Example Data Product
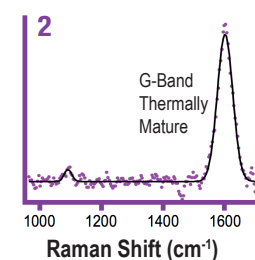

Context Image of Fig Tree Chert

Macroscopic Image

Fluorescence Map

1 mm

No Organics   Mature Organics   Low Volatility Organics

DUV Fluor: Organic Detection, Classification, & Distribution

1
Crystaline SiO$_2$ G-Band Less Thermally Mature
C=C
1000 1200 1400 1600
Raman Shift (cm^{-1})

2
G-Band Thermally Mature
1000 1200 1400 1600
Raman Shift (cm^{-1})
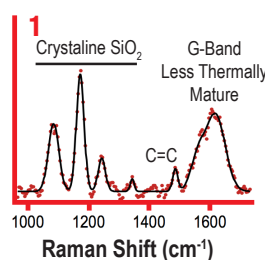
DUV Raman: Organic analysis & mineralogy

Summary

- Double or triple the number of Mars landers at small additional cost for each mission opportunity.

- Target high-risk locations, including canyons and crater walls.

- Distributed science from multiple sites simultaneously.

- Allow heavy university and small business involvement, at a level just now starting with beyond-Earth CubeSats.

Contact: *robert.l.staehle@jpl.nasa.gov*
818 354-1176

Prior MarsDrop References

1. Matthew A. Eby, "MarsDrop," *Second Interplanetary CubeSat Workshop*, Ithaca, NY 2013 May 25.
2. Robert L. Staehle, Matthew A. Eby, Rebecca M. E. Williams, Kenneth Williford, Manuel de la Torre Juarez, "MarsDrop Architecture: Landing Microprobes at Exciting Sites on Mars," conference paper for *65th International Astronautical Congress*, Toronto, Canada 2014 October 3.
3. Robert L. Staehle, Matthew A. Eby, Rebecca M. E. Williams, Kenneth Williford, Manuel de la Torre Juarez, Rohit Bhartia, Justin Boland, Courtney Duncan, Travis Imken, "MarsDrop Architecture: Landing Microprobes at Exciting Sites on Mars," presentation at *65th International Astronautical Congress*, Toronto, Canada 2014 October 3.
4. Frank Morring, Jr., "Getting Down: Parawings could land piggyback microprobes on Mars," *Aviation Week & Space Technology*, 2014 October 20.

Additional Information

Backup Slides

Developing a Landing Architecture for a Planetary Microprobe

Objectives/Motivation

The ability to land a small scientific package on Mars could unleash a wave of exciting exploration missions. Science on a global scale, at low cost, allowing for bold mission ideas that will augment and complement the flagship Mars programs.

Aerospace & JPL have flown 20 small satellites over the past 15 years, including reentry probes (REBR). The addition of a landing system to our reentry probes creates a new route for planetary research.

Project aims to architect & demonstrate a proof-of-concept landing system for a Mars microprobe, while preserving sufficient volume for a useful scientific payload.

Mars Microprobe Landing Architecture:
- Small hitchhiker payload riding with a host craft to Mars
- Aeroshell based on the REBR form factor, stability on entry
- Subsonic deployment of a lifting parawing - low sink rate
- Sized to land a miniature (3kg) probe at the highlands

Entry Interface
100 km, V=7km/sec

T+1 min, Max Q
35 km, 15 g's

NASA Parawing (courtesy NASA)

Approach

High altitude drop testing using weather balloons provides unmatched test fidelity for demonstrating the landing design.
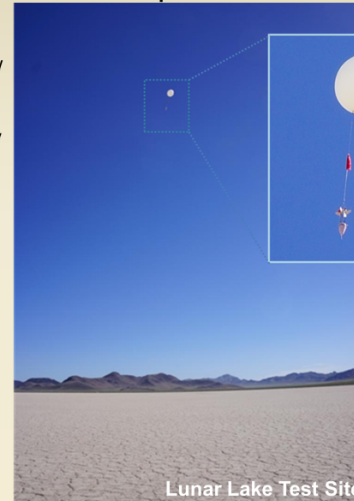
100,000 feet above Earth is a Martian Atmosphere:
- It's quite cold (-50°C)
- It's a near vacuum (99%)
- High velocity, subsonic flow

Test in stages:
- Launch, tracking, & recovery
- Parawing deployment
- Backshell separation
- Full proof-of-concept demo

Collaborate with community to transition to mission proposals.

T+3 min, Backshell Sep.

Lunar Lake Test Site

T+3 min, Main Deploy
6.5 km, 200m/sec , 65 g's

T+10 min,
Flying a 20°Glideslope

Touchdown!
<3.0 km, Vertical < 7.5 m/sec

Significant Results

Internal research results…
- Detailed trade study defined a viable landing approach
- Technical interchanges amongst the technical community broader community at JPL to define potential missions
- Developed the ability to carry out high altitude tests, a useful capability that can benefit other projects
- Test and demonstration phase over several flights

Deployed Parawing at 100,000 feet

Impact

Landing architecture will pave the way for discussing new missions with planetary scientists:
- Missions to the never before visited highlands of Mars
- Bold high risk destinations, including the great canyons of Mars
- Atmospheric flyovers using long duration glides
- Distributed science simultaneously at multiple locations

Mars Talk at JPL with Dr. Williams

Summary/Bottom Line

A bold approach towards Mars exploration that seeks to enable new science on a global scale:
- Aiming for the first successful Mars microprobe lander
- And the first flying vehicle on another planet
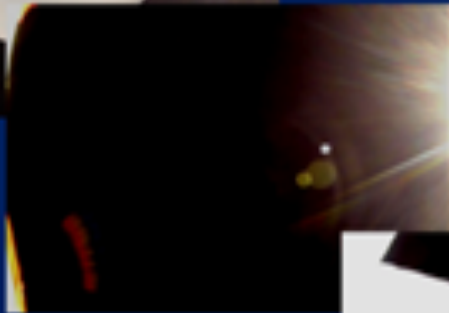- And the cheapest Mars vehicle

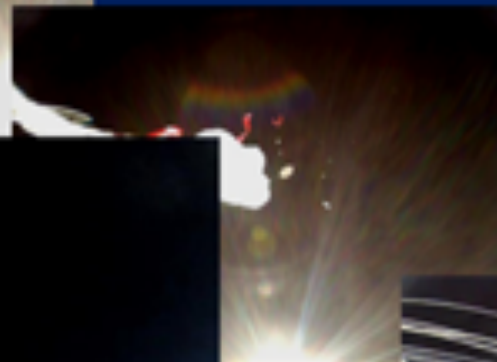# Parawing Deployment Test Sequence

100,501 feet, -40°C
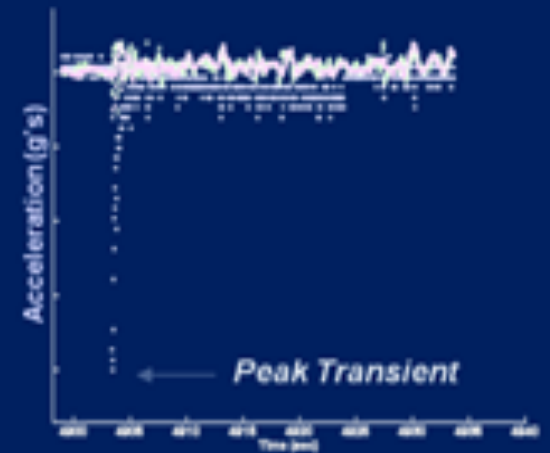
Balloon Release & Freefall
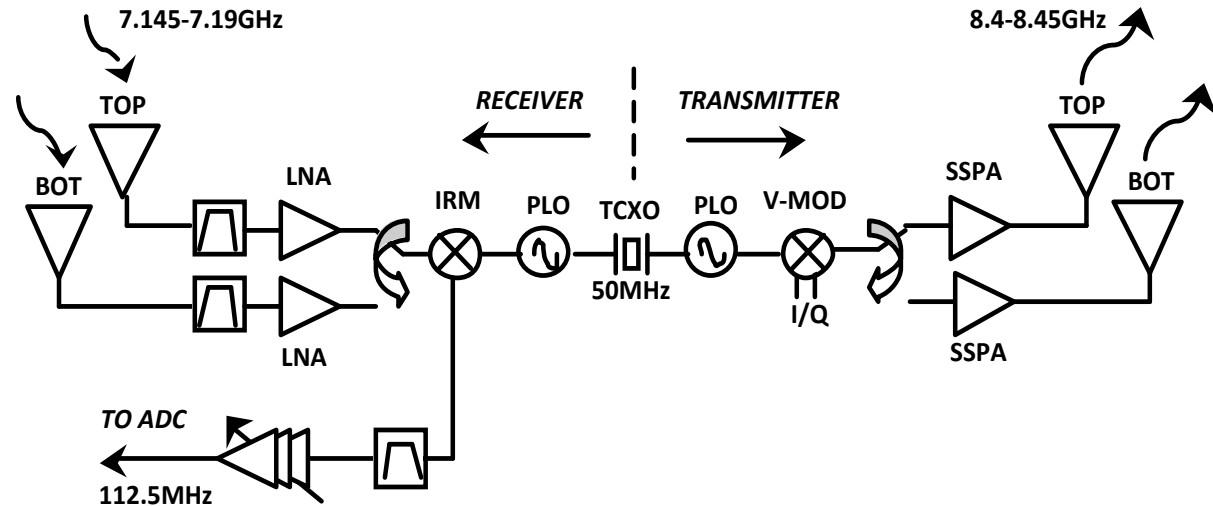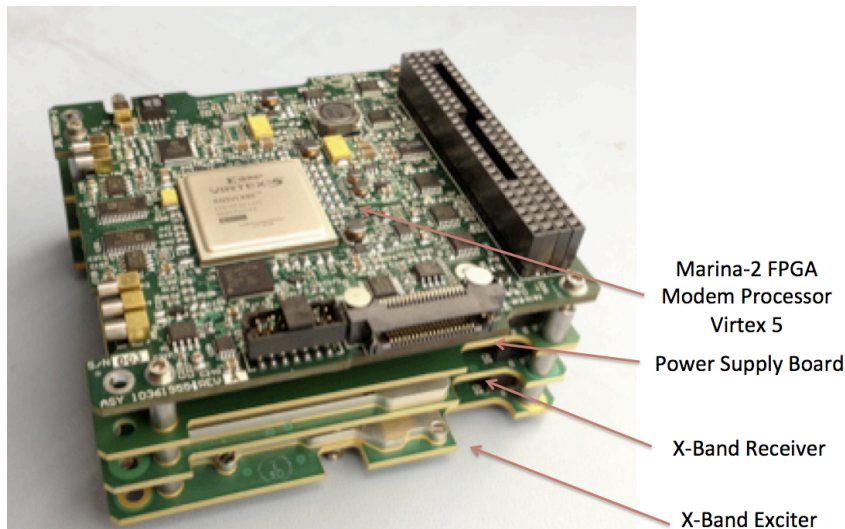
Cover Jettison, 300 mph, 200Pa

Chute Extension

Inflation

Example Payload: Iris X-band Transponder

~10 x 10 x 5 cm, <0.5 kg + antenna (less if UHF-only)

RF Block Diagram:

7.145-7.19GHz

TOP

BOT

LNA

LNA

RECEIVER

TRANSMITTER

IRM

PLO

TCXO
50MHz

PLO

V-MOD

I/Q

SSPA

SSPA

TOP

BOT

8.4-8.45GHz

TO ADC

112.5MHz

Iris Prototype Stack

Marina-2 FPGA
Modem Processor
Virtex 5

Power Supply Board

X-Band Receiver

X-Band Exciter

All functions and PLOs under FPGA control
All signal processing at baseband in FPGA
  - generation of transmit I/Q
  - processing of 112.5 MHz receive IF

POC = Courtney Duncan/JPL
courtney.b.duncan@jpl.nasa.gov

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Example Instrument:
Could we use a Go Pro Camera at Mars?

- COTS* Imaging solution for Mars?
  - *<2 W during imaging*
  - *<150 g in default configuration, including housing*
  - *~60 mm wide*

- On Earth, can provide images up to 12MP or 1080p video
  - *f/2.8 lens with diagonal FoV configurable to be 115 or 150 deg*

- Spatial resolution during descent
  - *Spatial resolution (not counting smear) in the 5MP (2560x1920px) mode. 5MP was baselined because it is the smallest file size generated by the GoPro:*

- Modifications likely required:
  - Materials compatibility.
  - Modest rad tolerance (<~10 krad).
  - Thermal tolerance or heater.
  - Voltage & data interface tbd.

*COTS = Commercial Off-the-Shelf

Slant Range	Spatial resolution
15km	12m
10km	9m
5km	4m
1km	0.8m
100m	8cm
10m	8mm

(POC: Travis Imken: Travis.Imken@jpl.nasa.gov)

Beyond Mars

- Concept equally applicable to planetary atmospheres thicker than Mars: Earth, Titan, Venus

  - *Titan, in particular, has a variety of terrain, lakes, and potentially rivers; ability to send multiple probes to different sites is attractive.*